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7. A peculiarly shaped stone celt, and a leaden cross, found at Newry : presented by P. Brophy Esq., Dawson-street.

8. A number of copper coins : presented by Mr. James Murphy, Lombard-street.

9. Three tradesman's tokens, viz :—MacAvragh, of Belfast; Wilson, of Dublin; and Nicholls, of Maryborough; all found at the latter place : presented by the Rev John O'Hanlon, C. C., of Dublin.

10. A piece of a modern sword-blade; a very beautiful V-shaped flint arrow-head; and the under and two upper stones of one of those primitive hand-mills called grain-rubbers in Dr. Wilde's Catalogue, Part I., p. 104. The under stone has its loop on its side, and not on its back, which is usual in perfect specimens of this kind : presented by Colonel Edwards, of Fintona.

James O'Reilly, Esq., exhibited the following from the collection of J. Summers, Esq. :—1. A copper blade, of the scythe shape; length about $12\frac{3}{4}$ inches—Mr. O'Reilly cannot say where it was found originally; 2. A small brass or bronze spur, said to have been found at Dunshaughlin; 3. A steel or iron arrow-head; 4. One of several cinerary urns found on Tallaght Hill.

The thanks of the Academy were voted to the donors and exhibitor.

MONDAY, JUNE 23, 1862.

THE VERY REV. CHARLES GRAVES, D. D., President, in the Chair.

ON the recommendation of the Council, it was

RESOLVED,—To authorize the Treasurer to sell out so much of the Cunningham Fund Stock as will produce £61 4s. 4d., to pay the difference between the cost of the four Cunningham Medals lately awarded, and the half-year's interest on the Stock, now due : the amount to be sold out being part of the amount of Interest added to the Capital Stock since the former award of Medals in 1858.

The Rev. Dr. LLOYD read a paper—

ON THE PROBABLE CAUSES OF THE EARTH-CURRENTS.

IN a former communication to the Academy, I endeavoured to prove that the diurnal changes of the horizontal needle were the result of electric currents traversing the earth's crust. The existence and continuous flow of such currents had been established, as I believe, by the observations of Mr. Barlow, made on two of the telegraphic lines of England; and it only remained to show that their laws corresponded with those of the magnetic changes. This part of the solution of the problem has, I venture to think, been given in the paper above referred to.

In that communication I refrained from offering any conjecture as to the origin of the currents themselves. Every speculation of this kind must remain a pure hypothesis, until it can be confronted and compared with facts; and the magnetic phenomena presented at different points of the earth's surface are so diversified, that a wide collection of the facts is necessary in order to form the basis of any sound physical theory. For these reasons, I have deemed it the more proper course to ascertain the *laws* of the diurnal changes of the Earth-currents at many places, so far as they may be inferred from the magnetic phenomena which they produce, before proceeding to the consideration of their *causes*. This procedure is in accordance with the acknowledged rules of the inductive philosophy; and the departure from it has given rise to speculations on this subject, which, however well they might accord with the phenomena with which they were compared, could not have been admitted for an instant in the presence of a wider generalization.

It has been shown, in the paper referred to, that the Earth-currents, as inferred from the changes in the two horizontal components of the magnetic force, observe certain general laws, which are common to all the stations at which these changes have been observed; while, on the other hand, their departures from a common type are various and considerable. We thus learn that the phenomena are produced by a common cause, the effects of which are greatly modified by the physical peculiarities of the parts of the earth where they are observed. The following are the principal features of the phenomena common to all, or to most of the places of observation.

I. The point to which the resultant Earth-current is directed follows the sun, although not at a uniform rate, throughout the day. In the northern hemisphere its direction is *eastward*, on the average, at 10^h 30^m A. M.; *southward*, at 2^h 30^m P. M.; and *westward*, at 7 P. M.

II. The *intensity* of the current is *greatest* between noon and 2 P. M., the mean time of the maximum in the northern hemisphere being about 1^h 30^m P. M. The intensity of the current is *least* at an interval of about twelve hours from the epoch of the maximum; and the direction of the current of least intensity is, in nearly all cases, opposite to that of the greatest.

III. There are two subordinate maxima, separated from the principal maximum by intervening minima. The morning maximum occurs, on the average, at 8^h 30^m A. M. It may be traced in the diurnal curves of the American and Siberian stations, and in those of the Cape of Good Hope and Hobarton. The current is then northerly in the northern hemisphere, and southerly in the southern. The evening maximum occurs at about 10 P. M., and is observed at almost all the stations.

The foregoing facts leave no doubt that the sun is the primary cause of the currents; and the only question is as to the mode of its agency. Upon this point I concur with Dr. Lamont in believing the electrical currents (or waves) on the earth's surface to be due to disturbances of

equilibrium of statical electricity; but I regard these derangements of equilibrium to be simply the effects of solar heat, and not (as Dr. Lamont believes) the results of an electrical force emanating directly from the sun.

It is well known that the earth and the atmosphere are, in ordinary circumstances, in opposite electrical states—the electricity of the earth being negative, and that of the atmosphere positive. It is also known that the electricity of the air increases rapidly with the height, a few feet—and in some cases even a few inches—being sufficient to manifest a difference of electrical tension. The rate of this increase is very different at different periods of the day, the difference appearing to be due to the greater or less conductivity of the lower strata of the atmosphere, giving rise to a greater or less interchange of the opposite electricities.

Now, we have in this machinery, as it appears to me, means fully adequate to the production of the observed effects. If it be assumed that the sun produces these changes by its calorific action, the effects at any given place will depend upon the relative temperatures of the neighbouring portions of the earth's surface. The earth being, in its normal state, negatively electrical, this negative electricity will be greatest (or the positive electricity least) at the parts most heated; and there will, consequently, be a flow of electricity to these parts from the place of observation. Thus the varying azimuth of the current, which is directed towards the most heated parts of the earth's surface, is explained. The maximum intensity of current, at 1^h 30^m P. M., is also accounted for, that being the period of the day when the solar calorific action is most intense. It should be noted, however, that the magnitude of the effect will depend, not on the absolute temperature, but on its relative increase. It is, accordingly, greatest at those parts of the earth at which the increment of temperature corresponding to a given distance is greatest.

The secondary maxima are probably due to the recombination of the atmospheric and terrestrial electricities, through the medium of vapour in the lower regions of the atmosphere. The effects of this recombination in producing horizontal currents in the earth's crust will, of course, be differential only, and will depend on the excess of the positive electricity thus transported at the places on the same meridian which are nearer to the equator. In confirmation of this view, it may be observed, that the epochs correspond with those of the maxima of atmospheric electricity, as deduced by Quetelet from the observations made under his directions at Brussels, the morning maximum of atmospheric electricity, in summer, occurring at 8 A. M., and the evening maximum at 9 P. M.

The phenomena hitherto described are such as would take place if all the parts of the earth's crust were similarly constituted, and therefore similarly acted on by the solar rays. In order to be able to explain the diversity which exists in the magnetic phenomena at different places, we must know something more of the nature of the solar action, and of the mode in which electricity is developed by it.

The speculations respecting the origin of atmospheric and terrestrial electricity are various. Thus, De Saussure believed that this electricity was developed by evaporation, the vapour taking the positive electricity, and the water the negative; and this hypothesis, with some limitations, has been very generally admitted by physicists. On the other hand, M. de la Rive is of opinion that the origin of this electricity is to be sought in the chemical actions which he supposes to be going on in the interior of the solidified crust of the earth; and he thinks that evaporation acts merely by transporting one of the separated electricities, and carrying it into the higher regions of the atmosphere. But whatever be the correct view as to the force which develops the electricity, it seems to be granted that the separation of the two electricities, in the earth and the atmosphere, is the consequence of evaporation, the vapour carrying with it the positive electricity, and the vaporizing body retaining the negative. Now, it follows from this, that the effect produced will vary greatly with the distribution of land and water, and will be greatest, *ceteris paribus*, where they come into juxtaposition at the coasts of the great continents, especially where the coast-lines are in, or near, the meridian. The evaporation from the surface of the sea being much greater than from the land, the electricity will be most deficient at the former. Hence there will be a flow of electricity *from land to sea*, which will combine with, and often mask, that due to the sun's position alone.

Now this is precisely what happens. The most marked instance of the phenomenon which we possess is that afforded by the diurnal changes of the currents at St. Helena. There the currents (as I have already shown) flow *from* the coast of Africa during the hottest portion of the day, and *towards* it during the night. The influence of the form of the coast seems to be shown in the diurnal curve of the Cape of Good Hope, by the existence of *three maxima*, of which the principal is directed from the land, and the two subordinate along the lines of coast. At Hobarton, in Van Diemen's Land, the same influence is shown in the extension of the southern lobe of the curve, which is there nearly equal to the northern.

I have since calculated the direction and intensity of the currents at the Indian stations, and I find that the curves follow nearly the type of the St. Helena curve. Thus, at Singapore, for which place we possess the results of observation during the three years 1843-1845, the maximum of current intensity takes place between 10 A. M. and 11 A. M., and its direction is S. 80° W. At Madras, so far as may be inferred from the observations of a single month, the maximum takes place at noon; and the direction of the current is then nearly the same as at Singapore, viz. S. 78° W. At Simla, in the Himalaya, the maximum occurs also at noon; but the direction of the current of greatest intensity is more southerly, its mean yearly direction being S. 47° W. This is precisely what should happen according to the hypothesis, this being

nearly the direction of the line drawn to the nearest point of the coast.*

The variation in the epoch of the maximum intensity of the current, at different places, is also in accordance with the same principles; that epoch being earliest in islands, or places nearly encompassed by sea, and latest in the interior of the great continents. Thus it occurs at noon at St. Helena, and in the southern parts of the peninsulas of Hindostan and the Malaya; while it takes place at 2 P. M. at Catherinburg and Barnaoul, in the interior of Siberia. This accords with the laws of the sun's calorific action.

It will be seen, upon an inspection of the diurnal curves of the Earth-currents (Trans. Royal Irish Academy, vol. xxiv.), that at most of the northern stations, as well as at Hobarton in the southern, the *easterly* currents being greater than the westerly. I believe this effect to be due to the *disturbance-currents*, which (as I have already shown) have an easterly tendency. This preponderance of the easterly currents, however, is found to be greater at places—such as Greenwich, Dublin, Makerstoun, and Toronto—which are near an eastern coast, than at those places—such as Petersburg, Catherinburg, and Barnaoul—which are in the interior of the continent. The results, therefore, so far confirm the supposition above made.

There are, unfortunately, very few places situated near the *western* shore of a great continent, at which continued observations of the two magnetic elements have been made. I know of none, excepting Sitka, on the western coast of North America. The results at this station, however, confirm the view above stated,—the *westerly* currents being there greater than the easterly.

There are probably many other circumstances in the configuration and structure of the earth's surface which influence the direction and magnitude of the currents; but I incline to think that the principal one is that above stated, viz. the distribution of land and water in the vicinity of the place of observation. It may be, also, that this cause is sufficient to account for some of the peculiarities in the form of the diurnal curve noticed in my former communication, and there referred to other causes. Thus, it is not improbable that the *persistent* direction of the current at Munich, there referred to the influence of a mountain range, may be, in fact, the result of the proximity of the Adriatic Gulf, which lies nearly in the direction of the persistent current.

* These additional results oblige me to abandon the conclusion formerly derived from a more limited induction, that the direction of the current of greatest intensity is connected with the magnetic meridian of the place. From the facts which we now possess, it would appear that the currents affect a meridional direction in the higher latitudes, while they are nearly parallel to the equator within the tropics. This will be seen in a striking manner by comparing the directions of the maximum currents in India, above given, with those of the Russian stations in the northern part of the Asiatic Continent.

In the preceding remarks I have referred only to the *regular* diurnal changes. I believe that the irregular are produced by the same forces, but operating in a somewhat different manner. The regular currents are produced, as I conceive, chiefly by the separation of the two electricities by evaporation, under the action of the sun; while the disturbance-currents are caused by their rapid recombination, through the medium of moisture, in the lower strata of the atmosphere.* In connexion with this view, I will, for the present, merely refer to the fact which has been established by an examination of the mean effects of the magnetic disturbances (Proceedings, April 28, 1862)—namely, that the epochs of the maxima of the disturbance-currents depend, in their mean values, upon the sun's hour-angle, and are independent of the longitude of the place. This result is in accordance with the hypothesis which ascribes these currents to changes in the sun's calorific agency, and to the meteorological effects which these engender.

In the limits within which it is necessary to confine this abstract, I have been able only to refer to some of the leading facts in confirmation of the hypothesis which I have ventured to propose; and I am obliged to omit altogether all reference to the objections which will probably be raised against it. There is, however, one fact which appears at first sight to offer a formidable difficulty to its reception, and which it may be necessary to notice here. The regular magnetic changes are greater in summer than in winter; while with the electrical tension, and its changes, it is the reverse. This objection, however, disappears when it is viewed more closely. The physical quantity measured by our electrometers is not the *absolute* electric tension, but its *variation with the height*; while the electric changes which engender terrestrial currents are the variations as depending on *horizontal distance*. It is easily conceivable that these should not correspond. In fact, it is natural to suppose that in summer the zero-plane, which separates the two electricities, should rise considerably; and thus that the variations for a given increase of altitude (which probably diminish with the distance from that plane) should lessen, although the absolute tensions, as well as the changes in horizontal distance, may be greater.

It would be of importance, in reference to this inquiry, to institute electrical observations of a totally different kind from any which we now possess, and to measure the differences of tension as depending on horizontal distance. There seems to be no difficulty in the way of such observations,—at least none greater than those which present themselves in the ordinary observations of atmospheric electricity; and the results would probably do more to clear up the physical aspect of these complex and interwoven phenomena than any other observational means.

* This hypothesis as to the cause of magnetic disturbances is due to M. de la Rive; but his views respecting the laws of the resulting currents are, as I have elsewhere shown, inconsistent with the phenomena. The regular diurnal changes of terrestrial magnetism are ascribed by M. de la Rive to a direct electrical action emanating from the sun.